New metacode coding concept for improving PDP gray-scale quality

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Today, methods for power management of plasma display panels (PDP) have been developed in order to provide a maximum peak white for a given picture content with stable power consumption. However, the quality of the gray-scale portrayal with such concepts is far from the actual CRT standards. We have developed a new PDP encoding concept called Metacode to improve gray-scale quality during all power and contrast adjustment towards CRT level.

Keywords — PDP, gray-scale portrayal, power management, large-area flickering, judder.

1 Introduction: PDP gray-scale quality

Today, methods for power management of plasma display panels (PDP) have been developed in order to provide a maximum peak white for a given picture content with stable power consumption. Such a concept requires, for different picture contents, various sustain distributions between the sub-fields. In standard approaches, this distribution is done simply mathematically and proportionally to the sub-field weight. This standard concept introduces various artifacts in the gray-scale portrayal quality: lack of smoothness, inversions, and noise in dark areas. This paper will show how a model of PDP luminance behavior enables the suppression of any of these artifacts.

2 Background: PDP power management

High contrast is an essential factor for subjective picture quality of every display technology. On one hand, a high peak-white luminance is always required to achieve a good contrast ratio and, therefore, good picture performance even under ambient-light conditions. On the other hand, the success of a new display technology also requires a well-balanced power consumption. For every type of active display, increased peak luminance also corresponds to a higher power that flows in the electronics. Therefore, if no specific power management is done, the enhancement of the peak luminance for a given electronic efficacy will introduce an increase in the power consumption.

The main idea behind every type of power-management concept associated with peak-white enhancement is based on the variation of the peak luminance depending on the picture content in order to stabilize the power consumption to a specified value. This concept is shown in Fig. 1.

The concept described in Fig. 1 enables the avoidance of overloading of the power supply, as well as a maximum contrast for a given picture. Such a concept suits very well to the human visual system,[1] which is dazzled in the case of a full-white picture, whereas it is very sensitive to dynamics in case of a dark picture (*e.g.*, a dark night with a moon). Therefore, in order to increase the contrast of a dark picture, the peak luminance is set to very high values, whereas it is reduced in the case of luminous pictures (full white).

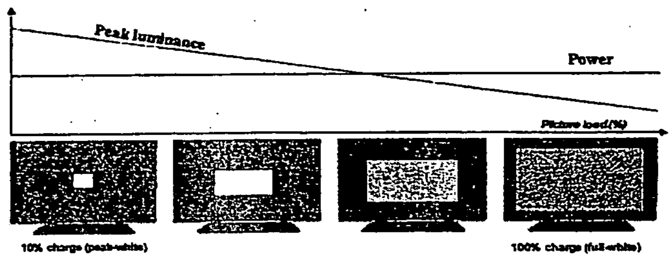

FIGURE 1 — General concept of power management.

In other words, for every charge in the input picture computed through the average power level (APL), a certain amount of sustain will be used for the peak white as shown in Fig. 2.

This has the disadvantage of allowing only a reduced number of discrete power levels compared to an analog system.

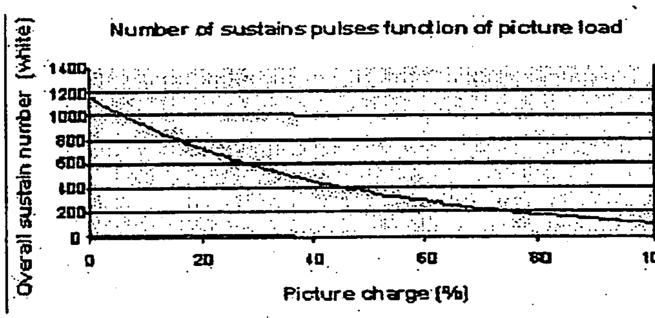

FIGURE 2 — Power management of PDPs.

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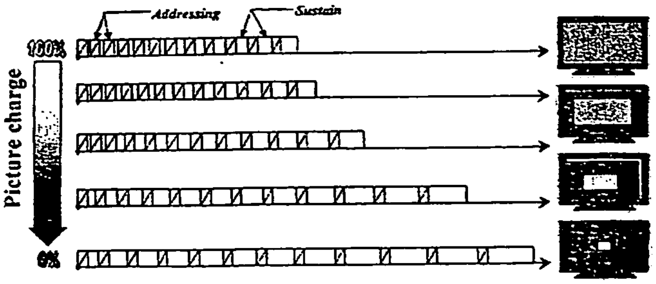

FIGURE 3 — Power management applied to PDPs.

The computation of the image energy (APL) is made through the following function:

$$APL[I(x,y)] = \frac{1}{C \times L} \sum_{x,y} I(x,y),$$

where $I(x, y)$ represents the picture to be displayed, C is the number of columns and L is the number of lines in this picture. Then, for every possible APL value, the maximal sustain to be used is fixed. This is illustrated in Fig. 3.

Actually, on almost all PDPs presently on the market, a low-quality gray-scale portrayal can be observed, depending on picture content. This is mainly due to the fact that it is difficult with the standard approach to distribute the available discrete number of sustains, keeping the relative sub-field weighting correct. This situation is explained in Table 1 which represents the sustain sequences for various APL levels at a given sub-field sequence based on a 12 sub-field Fibonacci[5,6] sequence: 1-2-3-5-8-13-19-25-32-40-49-58.

The concept presented in Table 1 is commonly used by the major plasma suppliers today. The first row presents the sub-field weighting, which is used to render any video level independently of the picture content and energy. In other words, the video value 3 will be coded by using the first and second sub-fields [110000000000], the video level 7 by using the second and fourth sub-field [010100000000] and so on. The first column represents the energy of the picture to be displayed and measured through the APL: 0% representing a black picture, whereas 100% represents a full white page. Then, depending on the power management principle presented in Fig. 2, the maximal number of sustains to be used is fixed and shown in the extreme last right column of Table 1.

TABLE 1 — Evolution of sustain sequence *vs.* APL.

Weight	1	2	3	5	8	13	19	25	32	40	49	58	Σ=255
APL	Number of sustain period per sub-field												Total
0%	5	11	16	27	44	71	104	136	175	218	267	316	Σ=1391
20%	3	7	10	17	27	45	65	86	110	137	168	199	Σ=875
40%	2	4	6	11	17	28	41	53	68	85	105	124	Σ=544
60%	1	3	4	7	11	17	25	33	43	53	66	78	Σ=341
80%	1	2	2	4	7	11	16	21	26	33	40	48	Σ=210
100%	1	1	1	2	4	6	9	12	16	20	24	28	Σ=124

Finally, this number has to be distributed between the sub-fields in order to keep this sub-field sequence coherent with the following formula:

$$Sustain(n; APL) = Weight(n) \times \frac{SustainTotal(APL)}{\sum_{i=1}^{i=12} Weight(i)},$$

where n represents the n^{th} sub-field, *Sustain* (n; *APL*) the number of sustain for this sub-field at the power level *APL*, *Weight* (n) its weight, and *SustainTotal* (*APL*) the maximal number of sustain for the current *APL* level. Obviously, only an integral number of sustain can be used per sub-field. For instance, in Table 1, for a totally white picture in the classical approach, 124 sustains should be distributed, leading to a first sub-field equal to the second one and also equal to the third one (one sustain).

This kind of distribution will have a dramatic impact on the gray-scale portrayal, its linearity, and smoothness.

3 Drawbacks of the classical approaches

3.1 Lack of rendered levels in dark areas

For the case of the APL value of 100% presented in Table 1, we can see that the first three sub-fields have exactly the same number of sustains, which means the same light emission. However, they should render three different video values (1,2,3). This phenomenon will lead to a reduction of the available rendered levels.

Moreover, since PDPs are linear displays, an artificial gamma function should be applied in order to compensate for the pre-correction actually applied to each source. Indeed, every kind of video source is pre-corrected in order to compensate the quadratic gamma behavior of a CRT. This artificial gamma function is given as follows:

$$I_{out} = 255 \times \left(\frac{I_{in}}{255}\right)^{\gamma},$$

where I_{in} represents the 8-bit input signal and I_{out} is the 8-bit signal to be displayed for $\gamma = 2.2$. Table 2 presents the gamma function for some input values:

Table 2 shows the critical issue of a digital gamma function, where decimal values are required as output whereas only integral numbers can be rendered. Indeed, only an integral number of sustain can be used to render a video level. Therefore, the use of dithering methods is mandatory to compensate that effect. In that case, by using the

TABLE 2 — Implementation of artificial gamma curve.

I_{in}	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0
I_{out}	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.7	1.8	1.98

input values.

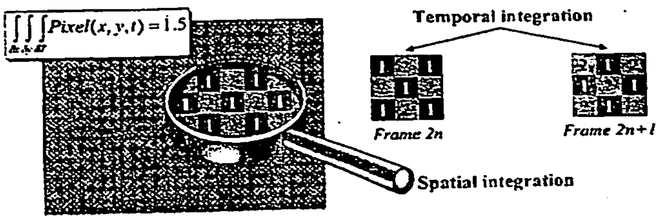

FIGURE 4 — Level 1.5 by spatio-temporal dithering.

spatial integration behavior of the visual system combined with its temporal integration, it is possible to render intermediate levels as shown on Fig. 4. In this example, a dithering function is used for the rendition of input level 25, requiring an output value around 1.5.

Figure 4 shows that it is possible to artificially render the value 1.5 by a spatio-temporal mixing of values 1 and 2. However, for the case of an APL value of 100% as shown in the example in Table 1, the value 1 and 2 have the same light emission (same sustain number). In that case, the dithering will be deactivated and all the video information contained in the input video values between 20 and 28 will be lost. Indeed, Table 2 shows that a dithering with 1 and 2 is mandatory in rendering all these input values.

This shows that, under certain circumstances, the standard power management and encoding approach will lead to a loss of information mainly for low levels. Indeed, the quadratic digital gamma function introduces the need for dithering to render dark levels, and the rounding used for power management will generate major problems for small sub-fields. Since the human visual system is very sensitive to information located in dark areas[3] this problem should not be underestimated.

Moreover, the lack of levels in the dark areas will increase the noise and, above all, the quantification noise in these areas, which is one of the major complaints of PDPs today.

3.2 Inversion in the gray scale

There is an additional problem of gray-scale fidelity appearing during actual power management known as "gray-scale inversions." A gray-scale inversion means that, under certain circumstances, a video level $N + 1$ could be darker than a video level N leading to disturbing gray-scale non-linearity.

The problem of level inversion can be easily explained by means of one example. In the situation presented Table 1, for an APL of 100%, video level 6 (111000000000) corresponds to three sustain pulses (1 + 1 + 1) and three writing operations. On the other hand, the video level 7 (010100000000) will also correspond to three sustains (1 + 2) but with only two writing operations. Since each writing operation brings an emission of light (around 20% of a sustain cycle), video level 6 will be lighter than video level 7.

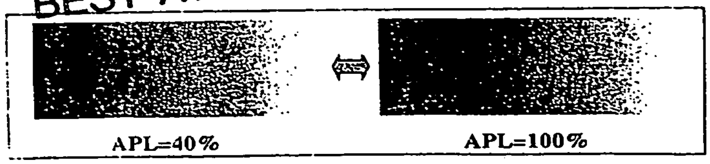

FIGURE 5 — Comparison between two APL renditions.

The apparition of such inversion will depend on the APL level, so that a change in the contrast, luminance, or picture content will introduce a new non-linearity in the gray-scale portrayal.

3.3 Final quality in terms of gray-scale portrayal

The previous paragraphs have shown that, for some power level (APL), the gray-scale portrayal can have various quality and artifacts. Therefore, the switch between power modes occurring during power adjustment (content change) or during luminance adjustment (user) is visible and disturbing. This is illustrated in Fig. 5 by comparing the two power levels of 40% and 100%:

Figure 5 shows a comparison between the gray-scale renditions for two different APL values (40% and 100%). On the left side, the quality obtained for APL = 40% is satisfactory, showing less inversions and missing levels, but on the right side, the quality obtained for APL = 100% is poor showing a lot of missing levels (steps in the gray-scale) as well as many inversions.

This document will now concentrate on a new concept to avoid such disparities in the gray-scale portrayal quality by using a new coding concept beyond standard ones: the Metacode coding concept.

4 Metacode encoding concept

4.1 Complete light-emission model

We have developed a new concept in order to avoid the disturbances in the gray-scale presented in the previous paragraphs. This concept is called Metacode since the developed coding method is "beyond" the standard one. In fact, this concept is based on a model of the light emission produced by all PDP stages, such as priming, erasing, writing, and sustaining. This concept also includes a model of the phosphor saturation for low-charged pictures (high peak white).

In order to illustrate the concept, the following model for cell behavior is taken as an example:

- Priming operation: 0.1 cd/m^2,
- Sustain pulse: 1 cd/m^2,
- Writing pulse: 0.25 cd/m^2.

The use of the priming light-emission model is important, since this operation defines the black level of the panel, which is a key parameter for the gamma-curve defi-

nition. The amount of priming used in a PDP can vary from one supplier to an other, but the use of only one priming operation per frame has already been presented[7] and will be used to simplify our explanation.

The APL table used for our example is derived from Table 1 and the following sustain table corresponding to an APL of 97% shall be considered:

$$1 - 1 - 2 - 3 - 4 - 7 - 10 - 13 - 16 - 20 - 25 - 30$$

$$(\Sigma = 132 \text{ sustains})$$

Now, the luminance model for a given code word can be defined as follows:

$$\mathit{Luminance(Codeword)} = \underbrace{0.1}_{\text{Priming}} + \overbrace{0.25 \times \underbrace{\underline{\mathit{Written}}}_{\text{Total number of writing operations}}}^{\text{Addressing}} + \overbrace{1 \times \underbrace{\underline{\mathit{Sustains}}}_{\text{Total number of sustain operations}}}^{\text{Sustaining}}$$

For example, the code word [110110100000] will correspond to one priming, five writing operations, and 19 sustains (1 + 1 + 0 + 3 + 4 + 0 + 10 + 0 + 0 + 0 + 0 + 0), which means $0.1 + 0.25 \times 5 + 19 = 20.35$ cd/m^2.

4.2 Code word to luminance mapping

For each given APL (97% in our example), a computation of the luminance level of all code word, is performed based on the previous defined model. Table 3 illustrates this principle. The overall luminance behavior is illustrated in Fig. 6.

Figure 6 shows the behavior of the luminance model for each of the selected code words.[4] The curve shows a great deal of inversions, plateaus and non-linearities.

For instance, Table 3 shows that there is already some code words that have equal luminance models such as the rows corresponding to numbers 1 and 2 or the rows corresponding to numbers 5 and 6. Furthermore, some inversions were already observed between the rows corresponding to numbers 3 and 4. Therefore, a reordering and modification of this table is mandatory.

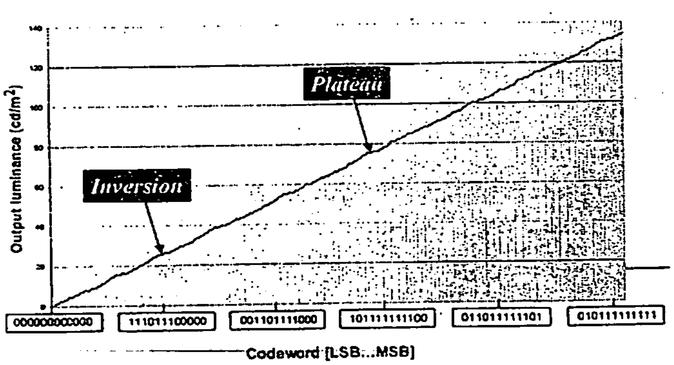

FIGURE 6 — Luminance *vs.* code-word behavior.

TABLE 3 — Sub-field code to luminance mapping.

Number	SF codeword	Luminance levels (cd/m^2)
0	0000 0000 0000	0.1 + 0x0.25 + 0x1 = 0.10
1	1000 0000 0000	0.1 + 1x0.25 + 1x1 = 1.35
2	0100 0000 0000	0.1 + 1x0.25 + 1x1 = 1.35
3	1100 0000 0000	0.1 + 2x0.25 + 2x1 = 2.60
4	0010 0000 0000	0.1 + 1x0.25 + 2x1 = 2.35
5	1010 0000 0000	0.1 + 2x0.25 + 3x1 = 3.60
6	0110 0000 0000	0.1 + 2x0.25 + 3x1 = 3.60
...		

4.3 Reordering and dropping

As explained in the previous paragraph, the next step in the Metacode concept consists of a reordering of the luminance codes in order to suppress inversion as well as plateaus. In order to do that, we will define new codes called luminance codes, corresponding to the new selected elements. Table 4 illustrates this principle.

In this stage, a new order #*N* is defined without any inversion or equality in luminance levels. In order to do that, the code word having equal luminance levels will be dropped while keeping the best code word in terms of response fidelity[7] and false-contour behavior.[2,4] This will lead to a new basic encoding table as shown in Table 5.

4.4 Ideal gamma-curve rendition

In the case of an APL of 97% as chosen in our example, the maximum luminance produced by the screen is $0.1 + 0.25 \times 12 + 132 = 135.1$ cd/m^2. Therefore, the ideal gamma function can be defined as follows:

$$I_{out} = 135 \times \left(\frac{I_{in}}{255}\right)^{\gamma} + 0.1$$

TABLE 4 — Luminance code reordering and dropping.

Number	SF codeword	Luminance	New luminance code
0	0000 0000 0000	0.10	#0
1	1000 0000 0000	1.35	#1
2	0100 0000 0000	1.35	Dropped
3	1100 0000 0000	2.60	#3
4	0010 0000 0000	2.35	#2
5	1010 0000 0000	3.60	#4
6	0110 0000 0000	3.60	Dropped
...			

TABLE 5 — New luminance encoding table.

Metacode	SF code word	Luminance (cd/m²)
#0	0000 0000 0000	0.10
#1	1000 0000 0000	1.35
#2	0010 0000 0000	2.35
#3	1100 0000 0000	2.60
#4	1010 0000 0000	3.60
...		

with $\gamma = 2.2$. This ideal gamma curve is illustrated in Table 6. Table 6 shows the desired luminance after the gamma function takes into account a black level of 0,1 and a white level of 132.1 (132 + 0.1). This new curve is illustrated in Fig. 7.

Figure 7 presents a new selection of the various code word from Fig. 6 called Metacodes, in order to perfectly suit the ideal gamma curve without any inversion or plateaus.

4.5 Final gray-scale rendition with dithering

Finally, we will encode the input levels by using the available selected Metacodes from Fig. 7 and the dithering algorithms.

In order to simplify our exposition, we will use in our further examples a 3-bit dithering concept. Such a concept enables us to dispose of eight different spatio-temporal mixes of two levels, *A* and *B*, as shown in Table 7.

Now, in order to finalize our concept, we will replace values *A* and *B* from Table 7 by our selected Metacodes *#N* to obtain a smooth and linear gray scale. The concept is illustred in Table 8.

Table 8 illustrates the overall principle of Metacode encoding, where the luminance of a selected code word is used in a shrewd way in order to achieve a linear and smooth gray scale without any inversion or loss of levels. This result is obtained for every APL mode so that the gray scale portrayal quality is maintained for all picture content or luminance adjustment. Furthermore, this guarantees a gamma behavior of the PDP very similar to the quality obtained by standard CRT technologies.

The overall concept will result in a smooth gamma curve rendition having inversion and no plateaus as shown in Fig. 8.

The new quality in terms of gray-scale portrayal for APL = 40% and APL = 100% is illustrated in Fig. 9.

This can be compared to the standard quality presented in Fig. 5. The difference in terms of quality is obvious. Moreover, this concept has been implemented in a prototype in our laboratory and was compared with standard products. It showed higher quality for video applications as well as for PC applications.

TABLE 6 — New implementation of artificial gamma.

I_{in}	0	22	29	34	41	49	100	150	200	255
I_{out}	0.1	0.7	1.2	1.7	2.5	3.6	16.9	41.2	77.4	132.1

TABLE 7 — Sub-level rendition with 3-bit dithering.

A	$\frac{7}{8}A+\frac{1}{8}B$	$\frac{6}{8}A+\frac{2}{8}B$	$\frac{5}{8}A+\frac{3}{8}B$	$\frac{4}{8}A+\frac{4}{8}B$	$\frac{3}{8}A+\frac{5}{8}B$	$\frac{2}{8}A+\frac{6}{8}B$	$\frac{1}{8}A+\frac{7}{8}B$

TABLE 8 — Metacode final encoding for APL = 97%.

Input levels	Expected luminance	Metacode rendered luminance
0	0.1	(#0) = 0.1
22	0.70	(4/8) × (#0) + (4/8) × (#1) = 0.72
29	1.21	(1/8) × (#0) + (7/8) × (#1) = 1.19
34	1.67	(6/8) × (#1) + (2/8) × (#2) = 1.60
41	2.47	(4/8) × (#3) + (4/8) × (#4) = 2.47
49	3.60	(#4) = 3.60
...		

5 Video adjustment to APL capabilities

Up to now, video information is displayed with 8-bit resolution for standard PDPs. The sub-field weights are chosen in order to be able to render these 8 bits with the best quality regarding the false contour effect.[2,4] This corresponds to a sum of sub-fields weight equal to 255.

However, we have seen in section 1, Fig. 2, a possible sustain evolution for various APL values. Some of these values are listed below:

- APL = 0% → 1391 sustains available,
- APL = 40% → 544 sustains available,
- APL = 80% → 210 sustains available,
- APL = 100% → 124 sustains available.

With these values it is easy to understand that there could be a miss adaptation between the available number of sustains and the picture resolution in terms of bits.

Indeed, with an APL = 100%, there are only 124 sustains which are available. In such a case it is impossible to render more than 124 real different levels.

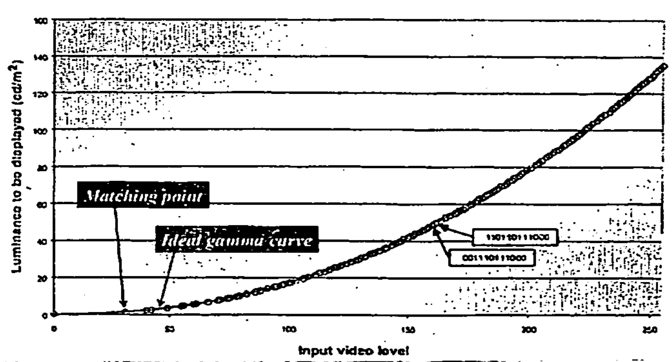

FIGURE 7 — Matching with an ideal gamma curve.

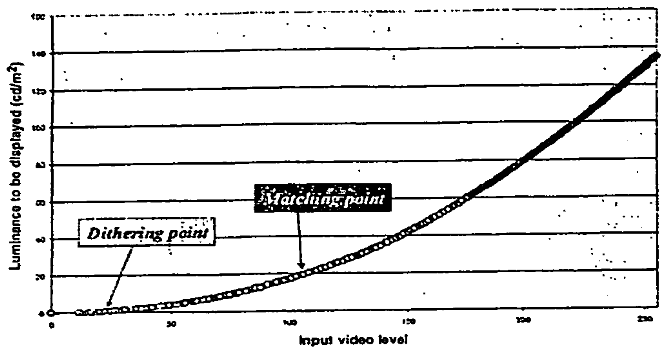

FIGURE 8 — Gray-scale rendition with Metacode.

Another problem is the situation in the dark areas while using only 8 bits of video rendition for an APL = 5% with more than 1000 sustains. In this case, the first sub-field will be very luminous (>4 cd/m^2) and all levels rendered with dithering using only this sub-field (input levels between 0 and 20) will be very noisy. This reduces the picture quality in dark areas, which is an actual weakness of PDPs. Furthermore, a low APL mode corresponds to a picture having less energy, being mostly dark, and which requires the best quality in the dark areas.

For all these reasons, the displayed picture dynamic (which is the ratio of the luminance of the largest available level to the luminance of the smallest one) should be adapted to the APL mode.

This is actually an underlying idea of the metacode!

The dynamic of the set of levels displayed on the panel will depend directly on the number of sustains. And the first sub-field will always use one single sustain (in order to have a dynamic as large as possible).

In full-white mode, the highest level has a luminance of 127 cd/m^2 (124 × 1.0 + 12 × 0.25) and the smallest one 1.25 cd/m^2 (1.0 + 0.25), so the dynamic will be equal to 101.6 (127/1.25). In peak white, the highest level has a luminance of 1393 cd/m^2 (1390 × 1.0 + 12 × 0.25) and the smallest one 1.25 cd/m^2 (1.0 + 0.25), so the dynamic will be equal to 1100 (1393/1.25).

This change in dynamic will have an impact on the dark area. Actually while the level of the highest input level is always set to the maximum level available (all subfields 'on'), the level of the smallest input level that can be displayed depends on the degamma function.

So the growth or the reduction in the picture dynamic through the sustain number during power adjustment has only an impact on the low levels.

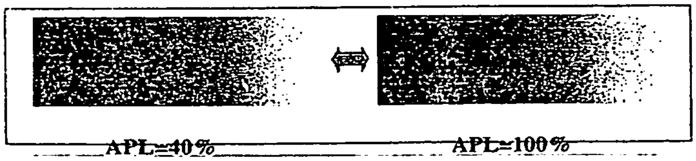

FIGURE 9 — Metacode rendition for two APL values.

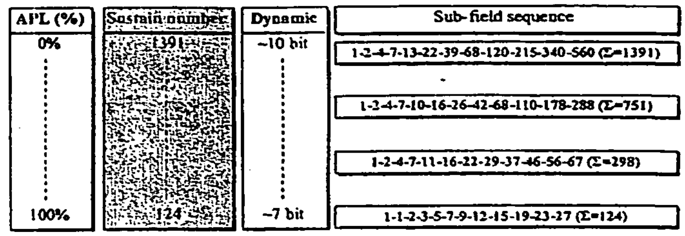

FIGURE 10 — Video/APL adjusted grayscale rendition.

In full white, the first level that can actually be rendered without dithering and will be 27 (127 × $(27/255)^\gamma$ + 0.1 ≈ 1), and 9 (1393 × $(9/255)^\gamma$ + 0.1 = 1) in peak white. For the case of standard coding, this level is always equal to 20 (255 × $(20/255)^\gamma$ + 0.1 ≈ 1) independently of the power management mode, but in full white many levels will be lost in the low levels as seen in session 3.1.

This adaptation of the dynamic of the set of the displayed levels to the number of sustains fully complies with the human visual system.[3] The full-white mode corresponds to bright signals, whereas peak white corresponds to dark signals. In the first case (full white), since the picture does not contain a lot of information in the dark area, no loss of level will be seen, and in the second case (peak white), the picture quality will really be enhanced by the growth of the dynamic showing levels which could not be rendered before.

Figure 10 shows that different video renditions will be used depending on the APL. Here only four sub-fields sequences are represented, but, in fact, there can be as many as different APL.

6 Conclusion

Based on actual PDP technology and standard driving signals, it has been possible by a simple new encoding concept called "Metacode" to improve the plasma gray-scale portrayal and its gamma behavior in order to reach actual CRT standards.

The main advantage in the concept presented here is the fact that it only requires signal processing based on new gamma function and a new encoding concept. There is no need to modify the actual electronics. This enables a visible picture-quality improvement at very low cost.

Acknowledgments

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Cédric Thébault received his engineering degree in telecommunications from the French "Grande Ecole" ENST Bretagne in 2000. In the same year he joined the Thomson Multimedia Research Laboratory in Villingen, Germany. He started his activities in the field of signal processing for plasma displays. His work in this area has resulted in more than 20 patents and patent applications, mainly in the field of plasma and flat display technology.

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